# Simplified Microwave Frequency Measurements
# Using the 10-MC Frequency Counter

THE -hp- Model 524A Frequency Counter was designed as a new type of secondary frequency standard capable of measuring frequencies up to 10 megacycles directly and automatically. The instrument differs from conventional frequency standards in that the measured frequency is displayed on a direct-reading system on the front panel and in that the instrument is complete in itself, requiring no external associated equipment. The indicating system identifies frequencies as high as 10 megacycles to eight significant figures so that a 10-megacycle unknown can be read to one-tenth of a cycle. Readings are accurate within approximately 2 parts per million ±0.1 cycle. Simplicity of operating the instrument is such that even the most inexperienced can make frequency measurements accurately and rapidly, for it is only necessary to connect the unknown and to record the reading displayed by the indicating system.
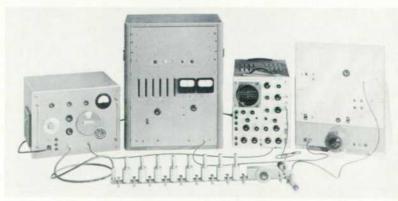
SEE ALSO A DISCUSSION ON PAGE 2 OF THE "PERFECT LOAD" AND THE NULL SHIFT

The Model 524A is being used in many interesting applications both for measurements within its direct-reading range as well as at frequencies well above its nominal 10-megacycle limit. Many of these applications make use of frequency dividers to divide the unknown frequency down into the range of the Model 524A. In one application in the -hp- plant, the Model 524A is used in a somewhat different way. This application makes use of the Model 524A to permit precise frequency settings of an oscillator in the 10-megacycle region. The output of the oscillator is then multiplied up to the microwave region for comparison purposes.

In the -hp- plant the Model 524A is used to calibrate the -hp- Model 530A waveguide frequency meters over a range from 5850 to 12,400 megacycles. The set-up for this work is diagrammed in Fig. 2. The frequency meter to be calibrated is inserted between the signal source and the waveguide tee. One arm of the tee connects to an -hp- Model 485B detector mount which provides a rectified signal for presentation on the oscilloscope. The second arm of the tee connects to a multiplier chain driven by the variable oscillator. The oscillator is provided with a high-ratio gear drive that varies the frequency over a range of a few hundred kilocycles on each side of 10 megacycles. The harmonic-generating system provides marker frequencies throughout the desired SHF range.
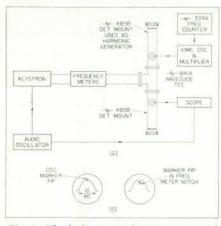


Fig. 1. Set-up for calibrating waveguide frequency meters using -hp- Model 524A Frequency Counter.

Fig. 2. *Block diagram of equipment used for calibrating waveguide frequency meters.*

In operation, the signal source is tuned to the desired region and is frequency-modulated to have a frequency swing of several megacycles. When the 10-megacycle oscillator is suitably tuned, a marker pip from the multiplier appears atop the klystron output curve as shown in Fig. 2(b). Now, when the frequency meter is approximately tuned to the marker pip frequency, a notch will appear on the oscilloscope presentation. When the frequency meter is precisely tuned, the marker pip will drop into the notch, giving an accurate indication of the frequency meter tuning.

The 10-megacycle oscillator can be slowly tuned through a range corresponding to the range of the frequency meter, pausing at desired intervals to establish the calibration. Throughout this process, the frequency of the klystron is changed to accommodate the marker pip.

Besides simplifying the calibration of the frequency meters, this test set-up allows convenient checks on drift caused by temperature changes and on shifts in resonant frequency caused by mechanical inaccuracies such as looseness of threads in the frequency meter drive system. Production tests on the frequency meters are further simplified by connecting a number of frequency meters in series. These are all connected between the klystron and the tee in a mass-calibrating arrangement.

## Q MEASUREMENTS

Use of the Model 524A also simplifies measurements of the Q of the meters. Since the notch is a plot of the resonance curve of the frequency meter, the Q can be quickly determined by measuring the frequency interval between the half-amplitude points of the notch. This is easily done by varying the 10-megacycle oscillator and recording the readings of the counter. Measurements with this arrangement give values of approximately 10,000 for the Q of the Model 530A waveguide frequency meters.

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# The "Perfect Load" and the Null Shift— Aids in VSWR Measurements

FREQUENTLY, the matter of how much of a measured VSWR value is attributable to the load and how much to the transmission system is important. In production work, for example, acceptance of a manufactured device may rest on being able to separate the VSWR of the transmission system from the VSWR of the device. If a device rated to have a VSWR not in excess of, say, 1.15 is measured in a system having a VSWR of 1.05, a resulting VSWR measurement slightly greater than 1.15 is not necessarily sufficient



Fig. 1. *-hp- Model X914A Sliding Load permits measurement of "residual" VSWR of transmission system to obtain more accurate VSWR measurements.*

reason for rejection of the device. On the other hand, a VSWR slightly lower than 1.15 may not be conclusive proof of performance. In very accurate work, also, where VSWR's in the order of 1.05 or less are being measured, it is usually important to determine the VSWR of the transmission system.

The "residual" VSWR of a transmission system in measurement work usually arises from the presence of one or more low-loss discontinuities. In VSWR measurements only the discontinuities between the sampling probe and the load end of the transmission system are considered, as long as the power source is well matched to the system. The discontinuities that cause the "residual" of the system are considered as a single lumped discontinuity, an assumption valid at a single frequency.

Two techniques are available to measure the "residual" of the system. One method involves measuring the VSWR of the system when terminated by a "perfect" or completely flat load. Although in the broadband sense such a load is unknown at present, it is possible to obtain the effect of a perfect load by means of a technique used in directional coupler work.

The "perfect load" is basically a well-designed load constructed in such a way as to be movable longitudinally in the transmission system. Such a load can be designed for either a coaxial or a waveguide system.

The basic philosopy underlying the use of the movable load is that reflections from the load can be identified from those caused by a discontinuity in the transmission
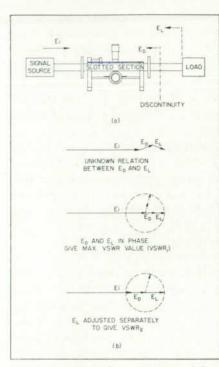
Fig. 2. *(a) Typical set-up using sliding load. (b) Relation of incident and reflected voltages when making measurements with sliding load.*

system. Where a discontinuity causes a reflection whose phase is fixed (provided frequency is held constant), reflections from the movable load can be made to occur in any phase by moving the load. In a typical VSWR measurement, moving the load will cause the meter pointer of the standing-wave indicator to vary as the phase of the reflection is varied.

To measure the VSWR of the transmission system, the sliding load is connected in place of the usual load at the end of the system. Then, adjusting both the position of the probe carriage on the slotted section and the position of the sliding load, the highest obtainable VSWR is sought and measured. This measurement requires some care, since the settings are interdependent.

Now, a second VSWR measurement must be made, using the former value for the maximum but a different value for the minimum. To make this measurement, first return the probe to the position of the original maximum or peak. Then adjust the sliding load to obtain a minimum reading on the standing-wave indicator. The load should be adjusted while the probe carriage is still positioned at the point of the former maximum. A second VSWR smaller than the first is thus obtained.

If the first VSWR reading is $VSWR_1$ and the second reading $VSWR_2$, the VSWR of the transmission system is

$$VSWR = \frac{VSWR_1}{VSWR_2} \quad (1)$$

The significance of the above measurements can be described by reference to Fig. 2(b), which represents the voltage waves in the transmission system in vector form. $E_i$, the incident wave, travels down the system and a partial reflection $E_d$ occurs at the discontinuity. A second partial reflection $E_L$ occurs at the sliding load.

The phase of reflection $E_d$ can, in effect, be adjusted by changing the position of the probe carriage on the slotted line. Similarly, the phase of reflection $E_L$ can be adjusted by positioning the sliding load. In the first VSWR measurement, the phases of $E_d$ and $E_L$ are adjusted by positioning the probe carriage and load so that the two reflections reinforce each other. This arrangement gives the highest obtainable value of reflected voltage and thus the highest VSWR. The VSWR has the value

$$VSWR_1 = \frac{E_i + (E_d + E_L)}{E_i - (E_d + E_L)}$$

In the second VSWR measurement, when the probe is returned to the position of the maximum, the phase of only $E_L$ is adjusted. Under this condition the reading has the value

$$VSWR = \frac{(E_i + E_d) + E_L}{(E_i + E_d) - E_L}$$

Since the reflected waves are small in magnitude, this second VSWR reading is essentially the VSWR of the sliding load. In case of question, the VSWR can also be calculated from the more accurate expression
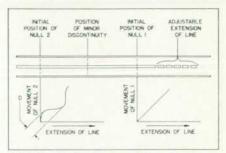


Fig. 3. *Effect of minor discontinuity on location of null when line is extended.*

$$VSWR = \frac{(VSWR_2) + 1}{(VSWR_2) - 1 + 2\frac{(VSWR_2)}{(VSWR_1)}}$$
$$\cong \frac{VSWR_1}{VSWR_2}$$

The sliding load is currently being manufactured for waveguide use over the frequency range from 8200 to 12,400 megacycles ($1'' \times \frac{1}{2}''$ waveguide). The load has a VSWR of 1.01 or less at all frequencies in this range. The load element is positioned by means of a handle at the back of the device.

**NULL SHIFT**

The second method commonly used for determining the "residual" VSWR of the transmission system is the null-shift method. The principles of this method are illustrated in Fig. 3, which shows a coaxial system terminated with a major discontinuity in the form of an open circuit. Located between the slotted section and the end of the transmission system is the minor discontinuity to be measured. Since the incident wave is totally reflected from the major discontinuity and since the minor discontinuity is lossless, the VSWR in the line is theoretically infinite under all conditions. Therefore, measurements of VSWR magnitude can not be used to provide information concerning the reflection coefficient of the minor discontinuity. However, such information is obtainable from the manner in which the phase of the reflection coefficient of the major discontinuity is affected by the reflection from the minor discontinuity. Specifically, informa-
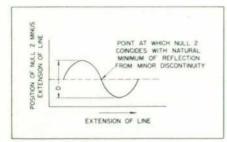
Fig. 4. *Null shift curve used to obtain phase data.*

tion concerning the reflection coefficient of the minor discontinuity is obtained from measurements of the position of the nulls in the standing-wave pattern.

If the end of the line is extended or lengthened in small increments, the position of the nulls between the minor discontinuity and the end of the line will move in identical increments. That is, the position of the nulls will be a linear function of line length. However, the nulls on the other side of the minor discontinuity will respond differently. Instead of moving linearly with extensions of the line, these nulls will follow a non-linear curve, as shown in Fig. 3.

This non-linear curve can be shown to be related to the reflection coefficient of the minor discontinuity[1]. By determining the peak-to-peak amplitude of the curve, the

VSWR of the minor discontinuity can be easily calculated.

To visualize the variations that occur in the position of the null, consider that in the usual case the discontinuity to be measured consists of a capacitive discontinuity shunting the line. If this discontinuity happens to occur at a null in the standing-wave pattern, it will have no effect on the system. If the discontinuity occurs at a voltage maximum, however, it will cause the line to be foreshortened. Thus, the position of the null in back of the minor discontinuity varies non-linearly as the line is extended.

The null shift can be measured with a set-up similar to that in Fig. 2(a). In place of the load in Fig. 2(a), the transmission system can be connected to a special section of rigid, air-dielectric coaxial line. The center conductor of the special line can be drilled and tapped to permit addition of extension segments for lengthening the line in known increments.

To measure the magnitude of the variations in the null, the positions of the null in the slotted section are plotted as the center conductor is progressively extended. When the line extensions are subtracted from the corresponding positions of the null, the resulting data will be a curve of the "null shift." From this data the residual VSWR of the transmission system can be calculated using the expression

$$\text{VSWR} = \frac{1 + \pi D/\lambda}{1 - \pi D/\lambda} \cong 1 + 2\pi D/\lambda$$

where D is the peak-to-peak amplitude of the null shift, $\lambda$ is the wavelength, and where D and $\lambda$ are in the same units.

The null shift method is usable in either coaxial or waveguide systems. As a practical matter, the method is better adapted to coaxial systems at frequencies in the range from a few

[1]Feenberg, E., "The Relation Between Nodal Positions and Standing Wave Ratio in a Composite Transmission System," *Journal. App. Physics,* Vol. 17, No. 6, p. 530, June, 1946.

hundred to a few thousand megacycles. At higher frequencies or in waveguide systems, the "perfect load" method is usually preferred because no displacement measurements are required and because the guide wavelength need not be measured. At frequencies in the order of a few hundred megacycles, however, the "perfect load" method requires an undesirably long tapered load.

**PHASE MEASUREMENT**

The "perfect load" and null shift methods are most often used to determine the magnitude of the small reflections occurring in the transmission system. However, both methods are also capable of providing useful information concerning the phase of the reflection.

In the "perfect load" method, phase information is quickly obtained by noting the position of the minimum in the standing-wave pattern when reflected waves $E_D$ and $E_L$ are in phase. Knowing the position of this minimum and the magnitude of the VSWR is usually sufficient to permit necessary compensations or to permit calculating how the residual VSWR of the system is affecting the measured VSWR of the load.

Phase information with the null shift method can also be easily obtained. When the null shift curve (Fig. 4) is plotted, the point where the null shift curve crosses its median in a positive-to-negative direction is the position of a minimum in the standing waves caused by reflections from the discontinuity.

　　　　　　—*J. K. Hunton* and
　　　　　　*W. B. Wholey*